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(54) IMPROVEMENTS IN AND RELATING TO APPARATUS AND METHODS FOR MAKING CABLES

(71) We, KABELWERKE BRUGG A.G. CH5200 Brugg, Switzerland, SOCIETE D'EXPLOITATION DES CABLES ELECTRIQUES (SYSTEME BERTHOUD, BOREL & CIE) (S.A.) CH-2016 Cortaillod, Switzerland, and SOCIETE ANONYME DES CABLERIES ET TREFILERIES DE COSSONAY, CH-1305 Cossonay, Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method and apparatus for the production of a high-tension cable comprising at least one conductor an insulation surrounding the. conductor, and a cable sheath, the insulation being made up from a plurality of insulating material tapes arranged one over another with an impregnating agent filling hollow spaces within the volume enclosed by the cable sheath, in particular intermediate spaces between adjacent insulating material tapes, and wherein the insulating material tapes extend with the longitudinal tape direction at least approximately in the longitudinal direction of the conductor insulated by them.

High-tension cables of conventional nature are known as so-called paper-insulated cables, in particular paper-insulated "oil cables". These known HT cables have proved very satisfactory in operation in respect of dielectric strength and durability, but have definite disadvantages caused by the paper insulation in respect to their electrical transmission properties, in particular a relatively high capacitance per unit of length resulting from the high relative dielectric constant (ϵ_r) of the impregnated paper forming the insulation, and an appreciable loss factor (tan δ) or rather a relatively great phase angle δ resulting from the upwardly limited insulation resistance of the paper insulation. Moreover, the production method for these known paper-insulated HT cables is complex and costly in view of the mechanical and physical properties of the cellulose paper used for insulation, this paper being extensible to only a very low degree and readily absorbing humidity. The easy absorption of humidity by the paper has the consequence that the paper insulation must be exposed to a drying process after being fully wound around the cable conductor before the impregnation of the insulation and the damp-proof sealing of the cable by the cable sheathing may be performed. The drying process is commonly performed under vacuum or considerably reduced pressure, and is relatively costly if only for this reason. A volumetric contraction of the paper is caused moreover by the drying process, which results in tensile and shear strains within the insulating windings, giving rise to the risk of cracks and wrinkles forming within the insulation during the drying process. In order to largely eliminate this risk, it is necessary to wind-on the paper tapes during the winding of the insulation, with a longitudinal pull which is sufficiently great on the one hand to preclude the development of wrinkles, in particular of wrinkles extending in the longitudinal direction of the tapes connected with a contraction in width of the tapes during the volumetric shrinkage, and which on the other hand and together with the tensile stress engendered in the longitudinal direction of the tape by the volumetric shrinkage still reliably remains below the tensile stress value at which the tapes break in view of the low extensibility of the paper. Since the complementary tensile stress caused by the volumetric shrinkage depends on the radial distance of the layer in question from the conductor, and since the tensile stress value at which the tapes break also varies moreover with the radial distance of the layer in question from the conductor because this tensile stress value depends on the tape cross-

section and the tape cross-section or rather the paper tape thickness must be substantially smaller close to the conductor than in the outer portion of the insulation on the score of electrical field intensity loading, the longitudinal pull required on the paper tapes during insulating winding differs from layer to layer. The accurate maintenance of these different longitudinal tractions matched precisely to the radial distance of the layer to be wound from the conductor and to the paper tape cross-section, requires a costly and complex apparatus comprising extensive controlling and governing devices, whereof the operating speed is already determined by the longitudinal tractions prescribed and cannot, therefore, be adapted to the operating speed of the other devices required for the production of the cable. Separate and non-combinable operating stages are consequently required for the insulating and subsequent drying, impregnating and sheathing operations during the production of paper-insulated HT cable, which implies another increase in technical comlexity of cable manufacture.

To summarise, for the known paper-insulated HT cables, their excellent qualities in respect of dielectric strength and durability are attained at the cost of a whole series of disadvantages in respect of the cable itself (high capacitance, high dielectric losses), as well as of its production method (several separate operating stages, drying process under vacuum, frequently also pre-drying of the paper tapes prior to winding-on), and of the production system required (complex insulation winding apparatus, vacuum drying system). As apparent from the preceding discussion, the properties of the paper used for insulation, namely a high loss figure $\varepsilon_r \cdot \tan\delta$, considerable humidity absorption and low extensibility, are the reasons for these disadvantages.

Consequently, it was an obvious step to attempt to replace the paper used until now as an insulating material in HT cables by another insulating material lacking the said disadvantages. The plastics materials applied to an ever increasing extent as insulating materials during the past decades, in particular the thermoplastic polymers and of these primarily poly-olefins, were on offer as such. It was discovered however that the simple replacement of the paper tapes by corresponding plastics material sheet tapes did not provide the required success. This is because although these plastics materials have substantially more advantageous properties in every respect in which the properties of paper led to the aforesaid disadvantages—such as a lower relative dielectric constant and a substantially lower loss factor than paper, a high degree of elastic extensibility and in particular also the property that they do not absorb any humidity from the ambient atmosphere in the short term—the plastics materials lack a property which is unavoidably required for the production of an operationally reliable HT cable in the manner established as conventional by paper-insulated HT cables, namely a porousness of the plastics material sheet tapes, which is intrinsically present in the case of cellulose paper. Because of this lack of porousness, impregnation in the manner customary until now is impossible with application of plastics material sheet tapes instead of paper tapes, because if the impregnation is undertaken after the winding of the insulation as in the case of the production of paper-insulated HT cables, air entrapped inclusions unavoidably formed within the insulating windings during the winding of the insulation, must be able to escape completely during the impregnating operation and this is possible only if the insulating material tapes are porous. In the case of non-porous tapes, such as plastics material sheet tapes no more than a part of the air can escape or rather be displaced by the impregnating agent, whereas the residual part of the air inclusions remains and results in electrical discharges occurring in these parts during operation of the HT cable, which lead to a breakdown of the cable in a short time.

A total elimination of air inclusions within insulation, of plastics material tapes is possible only if impregnation is carried out during the winding of the insulation. This possibility is ruled out in the case of the conventional helical winding of the insulating material tapes around the conductor or around the already applied part of the insulation, because the tape reels from which the insulating material tapes are driven for the winding of the insulation, must be carried around the conductor and the winding operation cannot, for this reason, be performed within a bath of impregnating fluid.

To make use of plastics material tapes as an insulating material and to be able to apply these to the conductor in an impregnating fluid bath, an attempt has already been made to apply the tapes to the conductor in such a manner that the displacement of the tape reels in the peripheral direction of the conductor (as required in the customary helical winding operation) may be omitted, and only relative displacement of the tape reels in the longitudinal direction of the conductor is required. An insulation of this kind,

comprising insulating material tapes of plastics material extending in the longitudinal direction of the conductor, is known from the HT cable described in the French Patent Specification 1,495,469. In its case, the insulation is applied on the conductor, in such manner that all tapes converge conically within an impregnating fluid container and are thus laid around the conductor. However, this method of applying the tapes results in relative movement between tapes in face to face contact as these tapes are nestled around the conductor and detailed investigations have shown this relative movement to lead to the forming of folds or wrinkles in the tapes which extend in the longitudinal direction of the tape and consequently to a heterogenous structure of the insulation. As a result, the dielectric strength of the HT cables thus produced is substantially less than that of comparable paper-insulated HT cables comprising insulating material tapes wound helically in conventional manner. Thus the initially highly promising attempts to make use of plastics material sheet tapes for insulation in HT cables instead of paper tapes was abandoned after unfortunate practical experiences with the experimental cables produced.

Another way of replacing the paper insulation in HT cables by a plastics material insulation, followed the line of incorporating a unitary thick-walled sleeve of plastics material as an insulation surrounding the conductor. In a structure of this kind, impregnation is unnecessary and the diffulties arising in respect of an unobjectionable impregnation of the plastics material insulation in the case of the application of plastics material sheet tapes instead of paper tapes, do not occur. It is also an advantage of this structure of the insulation that the plastics material sleeve may be applied on the conductor in an extrusion process which quite appreciably reduces the technical complexity and thereby the costs of the production of such a plastics material cable as compared to cables comprising an insulation consisting of wound tapes. This is particularly so because the omission of the impregnation and of the drying process needed for the paper insulation removes the need for a multi-stage operation in the production of the cable. The advantages of an uncomplicated technology and relatively low production costs are confronted however by a decisive disadvantage that the dielectric strength of such cables equipped with a solid plastics material insulation, and thus their durability, leave much to be desired under heavy load. The reason for this is the following:

Structural irregularities, like micropores, inclusions of foreign substances, hollow spaces, but also internal strains, crystalline superstructures within the texture etc., are quite generally endangered areas in the insulation of HT cables, in which ionisation and thereby conversion or decomposition processes, which then finally lead to breakdown of the insulation, may be caused by field strength intensity. The risk to the same is the greater, in this connection, the greater the extension of the area in the radial direction of the cable, because with the extension of the area in radial direction of the cable, the total voltage present across the area and thereby also the energy and number of the charge carriers generated by ionisation, and thereby again their destructive action, rise commensurately. In the case of an insulation made up in layers of insulating material tapes and treated with an impregnating fluid, the dimensions of the endangered areas are now limited in the radial direction of the cable to the thickness of the insulating material tapes in each case, and the thicknesses of the insulating material tapes are so dimensioned in accordance with the field strength prevailing in each case in the layer in question, that the voltage present across the layer is insufficient to maintain a spontaneous discharge in the impregnating fluid. If a discharge occurs in an endangered area of an insulating material tape, it will be quenched as soon as the area has grown to the full tape thickness and the impregnating fluid can consequently penetrate into the area and fill the same. In the case of a solid plastics material insulation, such discharges result in carbonisation and thereby in so-called short-circuiting of the areas in view of the absence of an impregnating fluid, and this has the consequence of an increase of the field strength in the vicinity of these areas, so that the areas grow continuously and form a bridge within a short time, which leads to breakdown of the insulation. In the case of a solid plastics material insulation, a dielectric strength comparable to the dielectric strength of insulations made up in layers from insulating material tapes could consequently be obtained only if it were possible to produce solid plastics material insulations of totally homogeneous structure, and this cannot be accomplished with an extrusion process in any event and may presumably hardly be accomplished in other ways at an economically justifiable cost. As a consequence, HT cables having solid plastics material insulations have sofar only been used on a large scale for voltages in the lower part of the HT range, that is for voltages below 100 KV.

On the whole, it has thus been impossible

until now to achieve a success in devising HT cables having a dielectric strength and durability comparable to the paper-insulated HT cables, which are free of the disadvantages of the known HT cables such as the high capacitance, the high loss factor and the technical production difficulties caused by the humidity absorption of the paper and by its lack of extensibility. From the foregoing, it can be seen that success is not likely to be accomplished with a solid plastics material insulation, but is more likely with an insulation produced in layers from insulating material tapes, provided that a satisfactory solution can be discovered for the problem of an unobjectionable impregnation while achieving a crease-free application of the insulating material tapes.

According to the invention, there is provided a method for the production of a high-tension cable comprising a core of at least one conductor, an insulation surrounding the core, and a cable sheath, the insulation being made up of a plurality of insulating material tapes laid lengthwise along the core with their longitudinal edges juxtaposed to form a plurality of concentric layers with the juxtaposed tape edges in each layer being circumferentially staggered with respect to the juxtaposed tape edges in the or each adjacent layer, the insulation being impregnated with an impregnating agent filling interstices between adjacent insulating material tapes, the method comprising moving the core through a working zone in which the insulating material tapes making up the insulation are drawn from tape reels by, and are laid along the moving core in such a manner that each successive tape layer is applied at a respective station in the working zone with the juxtaposed tape edges in each layer being staggered in the peripheral direction of the core with respect to the juxtaposed tape edges in the or each adjacent layer, the insulating material tape or tapes corresponding to one and the same layer being fed to the cable being formed in uniform distribution with respect to its periphery, and each insulating material tape unwinding from its tape reel in approximately plane form and being curved in its transverse direction prior to application to the cable under formation in such manner that at the moment of being applied, the tap fits snugly across its full width around the cylindrical surface of the cable being formed, the method further comprising impregnating the insulation with impregnating agent simultaneously with the application of the insulating material tapes forming the insulation.

The present method enables insulating material tapes to be applied to a cable free of creases due to the curving of the tapes prior to their application into a form substantially corresponding to the corresponding layer diameter in the finished cable. Furthermore, the unobjectionable impregnation of the insulation is achievable by the simultaneous application and impregnation of the insulating material tapes, the application being for example carried out in an impregnating fluid bath. The present method enables plastics material tapes to be used to insulate high tension cables.

In the present method, the insulating material tapes are preferably applied on the core precisely parallel to the core axis. In this case, the application of the insulating material tapes within an impregnating fluid bath is connected with the minimum technical complexity. It is, however, also possible to apply the tapes with a helical lay by effecting a relative rotation between the tapes to be applied and the core of an angular velocity proportional to the longitudinal displacement speed of the core. In this case the insulating material tapes are applied on the core at respective angles proportional (in each case with the same proportionality constant) to the radius of the corresponding layer, the proportionality constant preferably being selected such that the angle between a longitudinal tape edge and the axial direction of the core is smaller than 5° for all insulating material tapes applied.

Preferably, each tape layer is made up of n insulating material tapes (where n is any positive integer, including 1, and is the same for each layer) and each tape is arranged to extend in the transverse direction of the tape around approximately $360°/n$ in the peripheral direction of the core. The insulating material tapes are preferably applied such that the juxtaposed tape edges in consecutive layers are staggered with respect to each other through approximately $120°/n$ in the peripheral direction of the core. Advantageously n has a value of 1, 2 or 3.

Insulating material tapes of an elastically extensible material are advantageously used in the present method, preferably of plastics material foils or elastically extensible paper or a combination of both. Insulating materials which are plastically extensible only in practice and not elastically, may also be used for the tapes however. By contrast, the difficulty arises in the case of practically inextensible materials, that cracks of the insulating material tapes may occur in the areas of elongation of the cable caused at the bending points of the finished cable.

The insulating material tapes may

advantageously be applied on the cable under formation, under longitudinal tension and with a strain lying within the elastic limit of each tape, so that no buckling but merely a contraction of the insulation (that is, of the insulating material tapes) occurs in the buckling areas of the cable set up at the bending points of the finished cable which is to be laid. The elastic strain of the insulating material tapes is therefore appropriately dimensioned proportionately to their radial distance from the axis of the cable in the finished cable, the elastic strain of the insulating material tapes of the outermost layer is made at most equal to half the strain corresponding to the elastic limit of the material.

Plastics material foil tapes, preferably being polyolefin tapes, are primarily applied as insulating material tapes in the present method. These may advantageously be exposed to a complementary pre-tempering treatment, preferably to a chemical or irradiatory action for cross-linking of their molecular structure, prior to application to the core to be insulated.

The cable in process of being produced is appropriately equipped with an external screening after the application of all the insulating material tapes. The external screening is preferably braided around the outermost layer of insulating material tapes, this external screening advantageously being applied during the same production stage as the application of the insulating material tapes in a section following the section of application of the insulating material tapes in the direction of displacement of the core. The cable in process of being produced is preferably also equipped with a sheathing after the application of all the insulating material tapes but during the same production stage in a section following the section of application of the external screening in the direction of displacement of the core.

It is advantageous moreover for the cable in process of being produced, to be moved in a straight line through the section in which all the production steps occurring during the same production stage are performed that is, application of the insulating material tapes, external screening, sheathing).

So that the insulation may receive the impregnating agent simultaneously with the application of the insulating material tapes, the core is advantageously led through an impregnating fluid during the application of the insulating material tapes, and the temperature of the impregnating fluid is maintained within a range in which the impregnating fluid is in the liquid state.

An insulating liquid of low viscosity, preferably cable oil, is appropriately used as an impregnating fluid for the production of an oil filled cable, and an insulating fluid of medium viscosity is used as an impregnating substance for the production of an external-gas-pressure cable.

An impregnating agent which is in a transitional state resembling lubricating grease between the liquid and solid states at a normal temperature of 20°C, (preferably being a highly viscous hydrocarbon of high molecular weight or a mixture of such hydrocarbons), may also be advantageously used.

An insulating gas, preferably being nitrogen or sulphur hexafluoride, may also be applied as an impregnating agent however, in the case of the production of an internal-gas-pressure cable, instead of such an impregnating agent which is in the fluid state during at least the application of the insulating material tapes, the core then being led through a gas container under overpressure which contains the insulating gas, during the application of the insulating material tapes and until the sheathing operation.

According to another aspect of the invention, there is provided apparatus for effecting the method of invention, comprising an impregnating tank for containing the impregnating agent, guidance means for guiding the core through the impregnating tank, entraining means for moving the core longitudinally through the impregnating tank, means for rotatably mounting the reels of insulating material tapes, guidance elements situated within the impregnating tank and corresponding in number to at least the number of the layers in the insulation, the guidance elements being arranged to guide and shape the insulating material tapes immediately prior to application to the cable under formation, the guidance elements comprising tape guiding surfaces with a radius of curvature at right angles to the direction of displacement of the insulating material tapes which decreases in the direction of tape displacement, to effect bending of the insulating material tapes prior to their application to the cable into a form at least approximately matching their transverse curvature in the insulation within the finished cable, the apparatus also comprising gauging elements which surround the cable under formation at respective locations within the working zone and have respective diameters corresponding to the final diameters of the already applied part of the insulation in the finished cable, each gauging element serving to gauge the already applied part of the insulation to its final diameter as the

cable under formation is drawn through the gauging element.

In a preferred form of the apparatus, the impregnating tank is followed by a device for application of an external screening around the cable under formation after it has left the impregnating tank; preferably this device is a wrapping mechanism for braiding the cable under formation. This device may then advantageously be followed by a sheathing mechanism. In cases where an insulating gas is used as the impregnating agent however, the gas-filled impregnating tank preferably also encloses the device for application of the external screening and extends up to the intake of the sheathing mechanism.

Preferably, the guiding means of the apparatus are arranged to guide the core in a straight line through all the systems included in the same production stage (that is, insulating material tape application, external screening, and sheathing).

The present apparatus advantageously incorporates controllable braking means arranged to brake the feed of the insulating material tapes towards the core from their respective reels whereby to set up a constant longitudinal tension acting on the insulating material tapes. Preferably the braking means are incorporated in the means for mounting the tape reels.

In respect of the said guidance elements for the insulating material tapes, it is advantageous having regard to technical complexity, to incorporate one guidance element for each layer of the insulating material tapes, the guiding surfaces of each guidance element being in the form of a funnel. Preferably, each guidance element has longitudinal guidance means for longitudinal guiding of each individual insulating material tape of the corresponding layer. If it is intended to accomplish a very high precision in the application of the insulating material tapes, it may be more appropriate however, to incorporate a guidance element for every insulating material tape to be applied, and to arrange the guidance elements corresponding to each tape layer uniformly around the core with elements corresponding to adjacent layers being staggered with respect to each other in the peripheral direction of the core in accordance with the desired angular offset of the juxtaposed tape edges in adjacent layers. Furthermore, the guiding surfaces of the guidance elements change from an at least approximately plane surfaces at the tape ingress to an at least approximately part cylindrical form at the tape egress.

To secure a high precision in the application of the insulating material tapes, it is also of great advantage for a gauging element to be incorporated for each layer of insulating material tapes, and for the individual gauging elements to be arranged immediately following the tape outlets of the guidance elements associated with the same layer; such an arrangement ensures that the already applied part of the insulation has the correct diameter upon application of the insulating material tapes of the next layer and this avoids transverse displacement of the insulating material tapes which would be required after their application in the case of an excessive diameter and which is positively linked with the risk of forming creases.

If an impregnating substance which is in the fluid state during at least the application of the insulating material tapes is used as the impregnating agent, the gauging elements may simultaneously act as scraping elements for scraping off surplus impregnating agent entrained by the insulating material tapes during passage through the impregnating agent and may preferably be constructed with a tapered profile.

According to a further aspect of the invention, there is provided a method for the production of a high-tension cable comprising a core of at least one conductor, an insulation surrounding the core, and a cable sheath, the insulating being formed by a plurality of insulating material tapes laid lengthwise along the conductor with their longitudinal edges juxtaposed to form, in cross-section through the cable, concentric layers of tapes or a multi-turn spiral of tapes, the method comprising moving the core through a working zone in which the insulating material tapes making up the insulation are drawn from tape reels by, and are laid along, the moving core in such a manner that each successive tape layer or spiral part turn is applied at a respective station in the working zone with the juxtaposed tape edges in each layer or turn being circumferentially staggered with respect to the juxtaposed tape edges in the or each adjacent layer or turn, each insulating material tape being curved across its width prior to application to the cable under formation such that at the moment of being applied the tape fits snugly around the cylindrical surface of the cable being formed, the method further comprising impregnating the insulation with an impregnating agent simultaneously with the application of the insulating material tapes forming the insulation.

A method according to the invention and apparatus embodying the invention, both for the production of a high-tension cable, will now be particularly described, by way of example, with reference to the

accompanying diagrammatic drawings, in which:—

Figure 1 shows a diagrammatical illustration of the apparatus;

Figure 2 is a perspective view of a section of an impregnating tank of the apparatus illustrating the application of a layer of insulating material tapes to a partly insulated core; and

Figures 3 to 6 are diagrams illustrating respective preferred arrangements of the insulating material tapes around the cable core.

The method and apparatus now to be described will be described with particular reference to the production of an HT cable having a core with a single conductor and an arrangement of insulating material tapes as illustrated in Figure 5, that is, an arrangement in which the cable, considered in cross-section, is provided with a plurality of concentric layers of tapes, each layer consisting of three tapes.

As shown in Figures 1 and 2, the apparatus comprises a conductor reel 1 from which the bare conductor 2 used for the production of the cable is unreeled and which is equipped within its mounting with a braking system—which is not shown—producing a controllable braking torque and intended to generate a longitudinal tension on the conductor 2, a deflector pulley 3 which is equipped within its mounting with a system—which is not shown—for measuring the force exerted on it by the conductor 2 and for derivation of a control signal from the force measured for the braking system within the mounting of the conductor reel 1 and causing a constant longitudinal tension on the conductor 2, and a trough-like impregnating tank 5 filled with fluid impregnating substance 4. The tank 5 comprises a number of tank sections 5_1 to 5_m corresponding to the number of layers of tapes of insulating material (or in the case of cables provided with an innermost and/or outermost layer of semi-conductive material, to the number of insulating tape layers together with the number of semi-conductive material layers) with which the cable is to be provided. Associated with each tank section 5_1 to 5_m are one or more tape reels 6; in the present example, three tape reels 6 are provided per section as each tape layer is to be formed by three tapes. Also associated with each tank section 5_1 to 5_m are deflector rolls 7 (three) and guidance elements 8 (three) for the three tapes arranged per layer in each of the tank sections 5_1 to 5_m, and one gauging and scraping element 10.

A chamber 11 encloses tank 5 and its associated equipment for application of the insulating material tapes. The chamber 11 has one inlet-side seal 12 and an outlet-side seal 13.

The apparatus further comprises a device 14 constructed as a wrapping mechanism for application of an external screening. The device 14 serves the purpose of wrapping a tape with a metal facing forming the external screening 16 around the insulation 15 applied on the conductor 2. Following the device 14 is a sheathing mechanism 17 for applying a lead sheath 18 over the external screening 16.

The apparatus is also provided with a doffing pulley 19 which, together with the deflector pulley 3, serves the purpose of guiding means for rectilinear guidance of the cable in process of being produced through the chamber 11 and the impregnating tank 5, the device 14 and the sheathing mechanism 17. The doffing pulley 19 is driven by a motor (not shown) at a turning couple kept constant by a control system in order to set up a constant longitudinal tension on the cable 20. The radius of the doffing pulley 19 corresponds to the minimum permissible radius of curvature of the cable 20.

The completed cable is wound onto a cable reel or drum 21 driven by a motor (not shown) at a torque which is small compared to the torque of the motor driving the doffing pulley 19 and which is kept constant by means of a control system.

The production of an HT cable in the apparatus shown in Figures 1 and 2 occurs in the following manner. The conductor 2 is drawn off the conductor reel 1 against the braking action of the said braking system incorporated in the mounting of the conductor reel 1 and not illustrated. The longitudinal tension on the conductor 2 required for this purpose is largely set up by the motor driving the doffing pulley 19, but also by the longitudinal thrust acting within the sheathing mechanism 17 and acting on the cable, and to a relatively small extent also by the motor driving the cable drum 21. A stranded copper conductor is used as a conductor 2, in the same way as in the known HT cables. The conductor 2 drawn off the conductor reel 1 is led over the deflector pulley 3 and by virtue of the longitudinal tension acting on it exerts a force on the mounting of the deflector pulley 3 which is measured by the device (referred to above) installed within the mounting of the deflector pulley 3. This device generates a control signal for controlling the braking system installed within the mounting of the conductor reel 1 in order to so control the braking torque on the reel 1 that a constant longitudinal tension on the conductor 2 results. From the deflector pulley 3, the conductor 2 is led

into the chamber 11 via the seal 12 and is fed therein into the trough-like impregnating tank 5 via another seal (not shown).

Between the deflector pulley 3 and the seal 12, the conductor 2 may also traverse a mechanism, not illustrated in Figure 1, for application of a so-called internal semi-conductor layer, which preferably comprises co-polymers containing carbon black and serves the purpose of smoothing the conductor or rather to prevent the forming of electrically stressed cavities between the conductor and the insulation. Instead of an application of the internal semi-conductor layer prior to the infeed of the conductor 2 into the chamber 11, one or more tapes of a semi-conductive material may be applied on the conductor 2 within the first tank section 5_1 to lie lengthwise axially of the conductor 2 and enwrap the conductor 2 in transverse direction with overlapping of their tape edges. To ensure that as the conductor 2 runs into the tank 5 and prior to the application of the first layer of insulating material tapes 9 or tapes of semi-conductive material, all externally accessible surfaces of the conductor 2 are properly wetted by the impregnating fluid (i.e. without forming cavities and air inclusions) and any externally accessible cavities are filled, the impregnating substance is kept in a highly fluid form in the impregnating tank 5 by heating and the path travelled by the conductor 2 in the impregnating tank 5 prior to the application of the first layer of insulating material tapes is made of an appropriate length. If the conductor 2 has a hollow center, e.g. as in the case of an oil-filled cable, the impregnating substance formed by cable oil in this case may be fed in from the cable end on the cable drum 21 into the conductor 2, and any cavities in the conductor 2 accessible from inside or outside will be filled.

A layer of insulating material tapes 9 is then applied on the conductor 2 fed into the impregnating tank 5, in each tank section 5_1 to 5_m (resp. 5_2 to $5_{(m-1)}$, if tapes of semi-conductive material are applied in the tank sections 5_1 and 5_m). The method of application is illustrated in particular in Figure 2. Figure 2 shows, in diagrammatical illustration in perspective of a tank section of the impregnating tank 5, the part of the cable in process of being produced which is traversing this tank section, the three insulating material tapes 9 appertaining to one layer of insulating material tapes in this case, their infeed from three tape reels 6 and via deflector pulleys 7 and guidance elements 8, said tape reels being situated side-by-side above the tank section and not shown in Figure 2, to the cable in process of being produced, as well as the gauging of the new layer formed by these three insulating material tapes 9 by means of the gauging element 10.

The insulating material tapes 9 are drawn off the tape reels 6 under longitudinal tension against the braking action of braking systems having a controllable braking torque, installed in the mountings of the tape reels 6 and not illustrated in the drawings, and by virtue of this longitudinal tension exert forces on the mountings of the deflector pulleys. These forces are measured and control signals are derived from them for controlling the braking systems within the mountings of the tape reels 6 which result in a control over the braking torques generated by these braking systems, of such nature that a constant longitudinal tension on the insulating material tapes 9 is the result. The device for measuring the forces exerted on the deflector pulleys 7 and for deriving the said control signals from these forces and also the mountings and securing elements for the deflector pulleys 7 have not been illustrated in Figure 2 for the sake of clear illustration.

The longitudinal tension on the insulating material tapes 9 is exerted by the cable in process of being produced, by its displacement through the impregnating tank 5 (from the right towards the left in Figure 2) and is so governed by the braking systems in the mountings of the tape reels 6 that it is identical for all insulating material tapes 9 appertaining to one and the same layer and causes an elastic strain of the same of at least 50 d/R%, where *d* denotes the diameter of the layer in question in the finished cable and R the minimum permissible radius of curvature of the finished cable. In the case of insulating material tape applied on the cable in process of being produced with an elastic deformation of this kind, no buckling arises at the buckling areas formed at the bending points of the finished cable to be laid, but merely a contraction of the insulation or rather of the insulating material tapes. It should be taken into account, however, with this magnitude of the elastic expansion of the insulating material tapes, which is proportional to the layer diameter *d* that the plastic strain of the insulating material tapes of the outermost layer should be equal to at most half the strain resulting at the upper limit of the range of elasticity, so that no cracks may occur in the insulating material tapes in the stretched parts of the cable formed at the bending points of the finished cable which is to be laid, nor any plastic deformations of the same. Plastic deformations of the insulating material tapes are undesirable in this connection

because the finished cable is bent not only whilst it is being laid, but also in the final stage of its production (doffing pulley 19) and upon being wound on to the cable drum, that is to say mostly with the minimum permissible radius of curvature, creasing may then occur of the insulating material tapes during the laying of the cable, in the areas in which plastic deformations of the insulating material tapes had occurred in the final production stage and upon winding on to the cable drum.

The insulating material tapes 9 elastically stretched as a result of the longitudinal tension acting on them run, as apparent from Figure 2, from the deflector pulleys 7 to the guidance elements 8 and are guided by these on to the cable in process of being produced and are simultaneously curved in such a manner in the transverse direction of the tape, that they bear with practically their whole width against the cylindrical surface 22 of the partly insulated conductor 2. Since the cable in process of being produced runs through the fluid impregnating substance 4 and the guidance elements 8 are also situated below the liquid surface of the impregnating substance 4, the insulating material tapes 9 run through the fluid impregnating substances prior to their application on the cable in process of being produced, and are wholly wetted by the same, so that an unbroken film of impregnating substance is formed upon applying the insulating material tapes 9 on the cylindrical surface 22 of the partly insulated conductor between the latter and the insulating material tapes 9 applied. The surplus of impregnating substance entrained by the insulating material tape 9 is concomitantly partially forced out laterally of the tapes 9 and drains off through the interstices between the guidance elements 8. After passing the guidance elements 8, the three insulating materials tapes 9 applied form a new layer between them, whereof the diameter is still a little greater however than the diameter of this layer in the finished cable, since the guidance elements 8 do not press the tapes 9 against the partly insulated conductor to prevent accumulations of the impregnating substance entrained by the tapes 9 in the lead-in gaps formed between the incident tapes 9 and the partly insulated conductor. To size the new layer to its diameter in the finished cable, the cable in process of being produced is consequently conveyed through the gauging element 10 after passing the guidance elements 8. The gauging elements 10 has an internal diameter corresponding to the diameter of the new layer in the finished cable and consequently performs the reduction of the diameter of the new layer to its diameter in the finished cable during the pulling-through of the cable in process of being produced. At the same time, the gauging element 10 acts as a scraper element for removal of the residual portions of the surplus of impregnating substance. This is forced out upon running into the gauging element 10 at the interstices between the insulating material tapes, the thickness of the said film of impregnating substance between the tapes 9 and cylindrical surface 22 of the partly-insulated conductor concomitantly being reduced in accordance with the diametrical reduction in the new layer formed by the tapes 9. By the end of the tank section, shown in Figure 2, of the impregnating tank 5, the cable in process of being produced has had added to it a fully impregnated layer of insulating material tape corrected to its diameter in the finished cable and runs into the next tank section in this state. It should also be stated with reference to Figure 2, that the guidance elements 8 and the gauging element 10 are so secured by means of fastening devices, which are not illustrated on the score of clearness, that the impregnating tank 5 may be lowered freely.

A layer of insulating material tapes 9 is applied on the cable in process of being produced, in each case in the individual tank sections of the impregnating tank 5, in the manner described above with reference to Figure 2. The insulating material tapes in consecutive layers are in the present example applied offset through 40° in each case in the peripheral direction of the cable in process of being produced, as shown diagrammatically in Figure 5. The guidance elements 8 and the deflector pulleys 7 are in each case correspondingly positioned in the individual tank sections with an offset of 40° with respect to the guidance elements and deflector pulleys in the preceding tank section. In this manner, the juxtaposed tape edges in each layer are circumferentially staggered with respect to the juxtaposed tape edges in the or each adjacent layer.

If it is intended to enwrap the insulation with a semi-conductive layer prior to the application of the external screening, one or more tapes of a semi-conductive material which have their longitudinal direction extending parallel to the axis of the conductor and enwrap the insulation in transverse direction with overlapping tape edges, may be applied in the final tank section 5_m instead of three insulating material tapes. If a semi-conductive layer consisting of a single tape only is applied in the tank sections 5_m and/or 5_1, the latter each incorporate no more than one tape reel, one deflector pulley and one guidance element, and the guidance element changes

from an approximately plane surface at the tape ingress to a cylindrical surface at the tape egress. As a rule, in the case of an application of tapes of semi-conductive material in the tank sections 5_m and/or 5_1, the number of tapes per layer will however be the same as in the case of the insulating material tapes or rather as in the tank sections 5_2 to $5_{(m-1)}$. The application of a semi-conductive layer enwrapping the insulation may however also occur in a mechanism (not illustrated in Figure 1) which is situated in the area between the seal 13 and the device 14 incorporated for the application of the external screening, or else within the device 14 itself and in a leading stage of the same, wherein the insulation is initially wound with a semi-conductive tape prior to the application of the external screening. In this case, however, care should be taken to ensure that no cavities or air inclusions are formed between the outermost layer of the insulating material tapes and the semi-conductive layer applied thereon, and that any interstices which may occur between this outermost layer and the semi-conductive layer are filled by the impregnating substance. This may be accomplished by making provision for the cable in process of being produced to run through the fluid impregnating substance along an additional path after application of the outermost layer of insulating material tapes and after traversal of the gauging element provided for this layer so that the finished insulation is externally completely covered by the impregnating substance, and that the internal diameters of the outlet-side seal of the impregnating tank 5 (not illustrated in Figure 1) and of the outlet-side seal 13 of the chamber 11, which are traversed by the cable in process of being produced, are formed a little greater than the diameter of the insulation, so that the film of impregnating substance formed by the aforesaid wetting of the insulating and surrounding the latter remains in being whilst traversing these seals and the semi-conductive layer to be applied thereupon may then, so-to-say be embedded in this film of impregnating substance. Another possibility of filling possible gaps between the outermost layer of insulating material tapes and the semi-conductive layer with the impregnating substance, consists in wetting the finished insulation again with the impregnating substance, before or during the application of the semi-conductive layer, and another possibility consists in arranging the device 14 in such manner that it is situated immediately behind the last tank section 5_m, and in arranging the gauging element for the last layer at the point of transition from the last tank section to the device 14 but whilst endowing said gauging element with a slightly larger internal diameter than the diameter of the insulation in the finished cable, and thereupon slightly compressing the insulation during application of the semi-conductive layer and concomitantly forcing the surplus of impregnating substance previously present between the ultimate and penultimate layers of the insulating material tapes into the gaps between the last layer and the semi-conductive layer.

After leaving the chamber 11, the cable in process of being produced then traverses the device 14 and is wound in the same with a tape having a metal facing and forming the external screening 16. A known wrapping mechanism, such as also used for application of external screenings in the known HT cables, may be used as the device 14.

After the device 14, the cable in process of being produced then traverses the sheathing mechanism 17 in which it is provided with the cable sheathing 18. A known sheathing mechanism, as also applied for application of the cable sheathing in the known HT cables, for example a lead press, may be used as a sheathing mechanism 17.

By contrast to the known methods for production of paper-insulated HT cables, in the present method the cable in process of being produced traverses the insulating chamber 11, the wrapping mechanism (device 14) and the sheathing mechanism 17 at the same speed so that a continuous production method is thus rendered possible, in which the insulating of the conductor, the screening of the insulation and the sheathing of the cable are performed in a single complete production stage. The speed of traversal of the cable in process of being produced, through the insulating chamber 11, the device 14 and the sheathing mechanism 17 is commonly determined by the sheathing mechanism.

The cable 20 leaves the sheathing mechanism 17 in the finished state and is then led over the doffing pulley 19 and is subsequently wound onto the cable drum 21.

The doffing pulley 19 is driven at constant torque by the motor already referred to in the foregoing and not illustrated. In the same way, the cable drum 21 is also driven by another motor which is not shown, at a constant torque which is substantially smaller however than the torque exerted on the doffing pulley 19. The magnitude of the longitudinal tension acting on the cable 20 is consequently and substantially determined by the torque exerted on the doffing pulley 19 and remains

constant since the former is constant. The operational diameter of the doffing pulley 19, as well as the minimum winding diameter of the cable drum 21, correspond to twice the minimum permissible radius of curvature of the cable 20.

Plastics material tapes, preferably polyolefin tapes, are commonly applied as insulating material tapes in the present method. The thickness of the insulating material tapes may increase from the innermost towards the outermost layer, in the same way as in the known paper-insulated oil-filled cables, but it may also be identical in all layers, the conditions applicable for the innermost layer then being decisive for the thickness of the insulating material tapes of identical thickness in all layers. As a rule, the same directives apply for the selection of the thickness of the insulating material tapes in the present HT cables as in the case of the known paper-insulated HT cables.

Preferred arrangements of the insulating material tapes, are shown in Figures 3 to 6. Figure 3, diagrammatically shows the arrangement of the insulating material tapes with one tape per layer, the tapes being staggered through 120° with respect to each other in each case in consecutive layers. Figure 4 shows an arrangement with two tapes per layer, the tapes in consecutive layers being staggered through 60° with respect to each other in each case. Figure 5 shows the already described arrangement with three tapes per layer, the tapes in consecutive layers being staggered through 40° with respect to each other in each case. Figure 6 shows an arrangement in which the insulating material tapes in cross-section through the cable form a multi-turn spiral with each tape extending over approximately 5/8ths of a turn (that is over approximately 225° around the cable periphery).

Regarding the impregnating substance to be applied in the present method, a highly viscous hydrocarbon in a transitional state resembling lubricating grease between the fluid and solid aggregate condition at 20°C, or a mixture of such hydrocarbons, is preferably applied as an impregnating substance. In this case, the impregnating tank 5 should be heated, so that the impregnating substance is maintained in the fluid state within the impregnating tank. The temperature of the impregnating substance to be maintained in the impregnating tank 5 should be selected such that the impregnating substance is in as easily flowable or rather highly liquid state as possible, while ensuring that the mechanical and chemical properties of the material used for the insulating material tapes, such as its elastic extensibility, its structural matrix, its chemical stability, etc., are not appreciably changed by being heated to the temperature of the impregnating substance. The latter is of special importance because plastics materials are primarily considered as the material for the insulating material tapes, and the thermal stability of plastics materials is limited, as is known.

The impregnating tank 5 moreover forms a part of a closed circuit of impregnating substance, wherein the impregnating substance is continuously circulated, purified and degassed.

WHAT WE CLAIM IS:—

1. A method for the production of a high-tension cable comprising a core of at least one conductor, an insulation surrounding the core, and a cable sheath, the insulation being made up of a plurality of insulating material tapes laid lengthwise along the core with their longitudinal edges juxtaposed to form a plurality of concentric layers with the juxtaposed tape edges in each layer being circumferentially staggered with respect to the juxtaposed tape edges in the or each adjacent layer, the insulating being impregnated with an impregnating agent filling interstices between adjacent insulating material tapes, the method comprising moving the core through a working zone in which the insulating material tapes making up the insulation are drawn from tape reels by, and are laid along, the moving core in such a manner that each successive tape layer is applied at a respective station in the working zone with the juxtaposed tape edges in each layer being staggered in the peripheral direction of the core with respect to the juxtaposed tape edges in the or each adjacent layer, the insulating material tape or tapes corresponding to one and the same layer being fed to the cable being formed in uniform distribution with respect to its periphery, and each insulating material tape unwinding from its tape reel in approximately plane form and being curved in its transverse direction prior to application to the cable under formation, in such manner that at the moment of being applied, the tape fits snugly across its full width around the cylindrical surface of the cable being formed, the method further comprising impregnating the insulation with impregnating agent simultaneously with the application of the insulating material tapes forming the insulation.

2. A method according to Claim 1, in which the insulating material tapes are applied to the cable being formed parallel to the axis of the core.

3. A method according to Claim 1, in which to obtain a helical layer of the

insulating material tapes around the core, the insulating material tapes to be applied are rotated relative to the cable being formed at an angular velocity directly proportional to the speed of longitudinal displacement of the core, and the insulating material tapes are applied to the cable under formation at respective angles to the axial direction of the core which are proportional with the same proportionality constant to the radius of the corresponding tape layer in the finished cable.

4. A method according to Claim 3, in which the said proportionality constant is so selected that for all insulating material tapes, the angle between a longitudinal edge of the tape and the axial direction of the core is less than 5°.

5. A method according to any one of the preceding claims, in which each tape layer is formed by *n* insulating material tapes where *n* is any positive integer, including 1, and is the same for each layer, each tape extending in the transverse direction of the tape over approximately 360°/*n* in the peripheral direction of the cable being formed and the juxtaposed tape edges being staggered in consecutive layers through approximately 120°/*n* in the peripheral direction of the cable being formed.

6. A method according to Claim 5, in which *n* has a value 1, 2 or 3.

7. A method according to any one of the preceding claims, in which the insulating material tapes are of an elastically extensible material.

8. A method according to Claim 7, in which the insulating material tapes are applied to the cable being formed under a longitudinal tension effective to cause only elastic strain of the tapes.

9. A method according to Claim 8, in which the elastic strain of the insulating material tapes is proportional to their radial distance from the axis of the cable in the finished cable, the elastic strain of the insulating material tapes of the outermost layer being no more than half of the strain corresponding to the elastic limit of the tapes.

10. A method according to Claim 7, Claim 8 or Claim 9, in which the insulating material tapes are plastics material tapes or elastically extensible paper tapes or a combination of both.

11. A method according to Claim 10, in which the insulating material tapes are polyolefin tapes.

12. A method according to Claim 10, in which the insulating material tapes include plastics material tapes, the plastics material tapes being subjected to a pre-tempering treatment prior to their application to the cable under formation.

13. A method according to Claim 12, in which the pretempering treatment involves chemical or irradiatory action for cross-linking of the molecular structure of the plastics material tapes.

14. A method according to any one of the preceding claims, in which after the application of all insulating material tapes, the cable under formation is provided with an external screening applied during the same production stage as the application of the insulating material tapes, and at a station following the said working zone in the direction of displacement of the core.

15. A method according to Claim 14, in which the external screening is wound upon the outermost layer of insulating material tapes.

16. A method according to Claim 13 or Claim 14, in which after the application of all the insulating material tapes a sheathing is applied to the cable under formation during the same production stage as the application of the insulating material tapes and at a station following the station at which the external screening is applied in the direction of displacement of the core.

17. A method according to any one of the preceding claims, in which the core is moved in a straight line through all said stations.

18. A method according to any one of the preceding claims, in which the core is passed through the impregnating agent during the application of the insulating material tapes and the temperature of the impregnating agent is maintained within a range in which the impregnating agent is in the fluid state.

19. A method according to Claim 18, in which the cable to be formed is an oil-filled cable and the impregnating agent is an insulating fluid of low viscosity.

20. A method according to Claim 18, in which the insulating fluid is cable oil.

21. A method according to Claim 18, in which the cable to be formed is an external-gas-pressure cable and the impregnating agent is an insulating fluid of medium viscosity.

22. A method according to Claim 18, in which the impregnating agent at a temperature of 20°C is in a transitional state, resembling lubricating grease, between the fluid and solid states.

23. A method according to Claim 21, in which the impregnating agent is a highly viscous hydrocarbon of high molecular weight or a mixture of such hydrocarbons.

24. A method according to Claim 16, in which the cable to be formed is an internal-gas-pressure cable and the impregnating agent is an insulating gas, the core being moved through a gas tank under overpressure wherein the insulating gas is

present, during the application of the insulating material tapes and until the sheathing operation.

25. A method according to Claim 24, in which the insulating gas is nitrogen or sulphur hexafluoride.

26. A method for the production of a high-tension cable comprising a core of at least one conductor, an insulation surrounding the core, and a cable sheath, the insulation being formed by a plurality of insulating material tapes laid lengthwise along the conductor with their longitudinal edges juxtaposed to form, in cross-section through the cable, concentric layers of tapes or a multi-turn spiral of tapes, the method comprising moving the core through a working zone in which the insulating material tapes making up the insulation are drawn from tape reels by, and are laid along, the moving core in such a manner that each successive tape layer or spiral part turn is applied at a respective station in the working zone with the juxtaposed tape edges in each layer or turn being circumferentially staggered with respect to the juxtaposed tape edges in the or each adjacent layer or turn, each insulating material tape being curved across its width prior to application to the cable under formation such that at the moment of being applied the tape fits snugly around the cylindrical surface of the cable being formed, the method further comprising impregnating the insulation with an impregnating agent simultaneously with the application of the insulating material tapes forming the insulation.

27. Apparatus for effecting the method claimed in any one of Claims 1 to 25, comprising an impregnating tank for containing the impregnating agent, guidance means for guiding the core through the impregnating tank, entraining means for moving the core longitudinally through the impregnating tank, means for rotatably mounting the reels of insulating material tapes, guidance elements situated within the impregnating tank and corresponding in number to at least the number of the layers in the insulation, the guidance elements being arranged to guide and shape the insulating material tapes immediately prior to application to the cable under formation, the guidance elements comprising tape guiding surfaces with a radius of curvature at right angles to the direction of displacement of the insulating material tapes which decreases in the direction of tape displacement to effect bending of the insulating material tapes prior to their application to the cable into a form at least approximately matching their transverse curvature in the insulation within the finished cable, the apparatus also comprising gauging elements which surround the cable under formation at respective locations within the working zone and have respective diameters corresponding to the final diameters of the already applied part of the insulation in the finished cable, each gauging element serving to gauge the already applied part of the insulation to its final diameter as the cable under formation is drawn through the gauging element.

28. Apparatus according to Claim 27, comprising one said guidance element for each layer of insulating material tapes, the guiding surface of each guidance element is in the form of a funnel.

29. Apparatus according to Claim 27, in which each guidance element incorporates longitudinal guiding means for longitudinal guiding of each individual insulating material tape of the corresponding layer.

30. Apparatus according to Claim 27, comprising a respective said guidance element for each insulating material tape to be applied, the guiding elements corresponding to the tapes of the same layer being uniformly distributed around the cable at the corresponding said station in the working zone and the guidance elements corresponding to adjacent layers being staggered with respect to each other in the peripheral direction of the core such as to effect the said staggering of the said juxtaposed tape edges between adjacent layers, the guiding surfaces of the guidance elements changing from an at least approximately plane surface at the tape inlet to at least approximately part cylindrical form at the tape egress.

31. Apparatus according to any one of Claims 28 to 30, comprising a respective said gauging element for each layer of insulating material tapes, each gauging element being situated immediately following the tape outlets of the guiding elements of the corresponding layer.

32. Apparatus according to any one of Claims 27 to 31, including controllable braking means arranged to brake the feed of the insulating material tapes towards the core from the respective reels whereby to set up a constant longitudinal tension acting on the insulating material tapes.

33. Apparatus according to Claim 32, in which the braking means are incorporated in the means for mounting the tape reels.

34. Apparatus according to any one of Claims 27 to 32, in which the impregnating tank contains a fluid impregnating agent and the gauging elements simultaneously act as scraper elements for scraping off surplus impregnating agent entrained by the insulating material tapes upon passing through the impregnating agent.

35. Apparatus according to one of the

Claims 27 to 34, in which the impregnating tank is followed by a device for application of an external screening around the cable under formation after it has left the impregnating tank.

36. Apparatus according to Claim 35, in which the device for application of the external screening is followed by a sheathing mechanism.

37. Apparatus according to any one of Claims 27 to 33, comprising a device for the application of an external screening to the cable under formation, and a sheathing mechanism, said device being situated following the section for application of the insulating material tapes in the direction of displacement of the core with the sheathing mechanism being arranged thereafter, the impregnating tank enclosing both the section for application of the insulating material tapes and the device for application of the external screening and extending up to the intake of the sheathing mechanism, and the tank being filled with an insulating gas under overpressure which constitutes the impregnating agent.

38. Apparatus according to Claim 35, Claim 36 or Claim 37, in which the said device for application of an external screen comprises a wrapping mechanism.

39. Apparatus according to any one of Claims 27 to 38, in which the guidance means are arranged to guide the core in a straight line during cable formation.

40. A method for the production of a high-tension cable, substantially as hereinbefore described with reference to Figures 1, 2 and 5 of the accompanying drawings.

41. A method for the production of a high-tension cable, substantially as hereinbefore described with reference to Figures 1 and 2 as modified by Figures 3, 4 or 6 of the accompanying drawings.

42. Apparatus for the production of a high-tension cable, substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

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1532648 COMPLETE SPECIFICATION

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Sheet 1

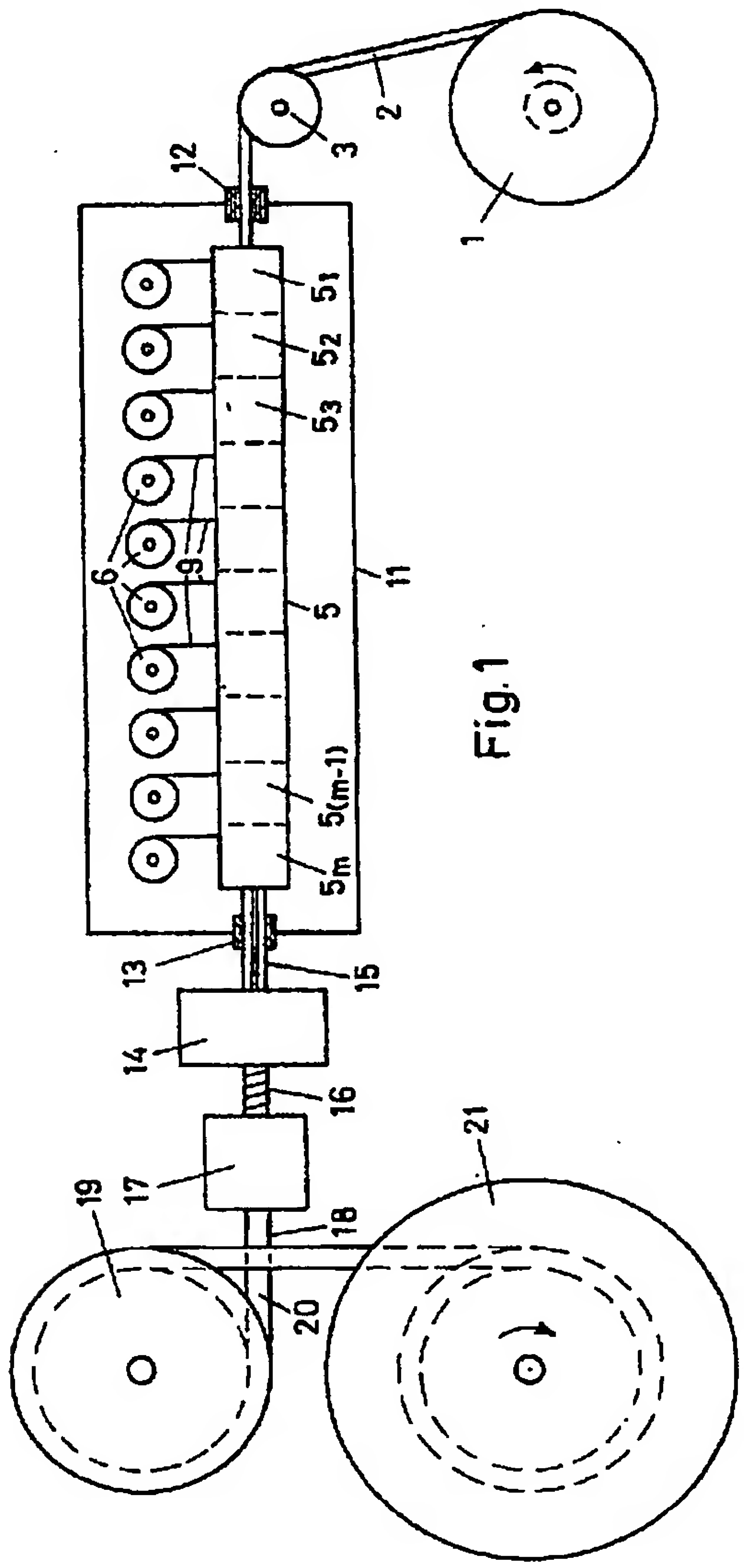

Fig.1

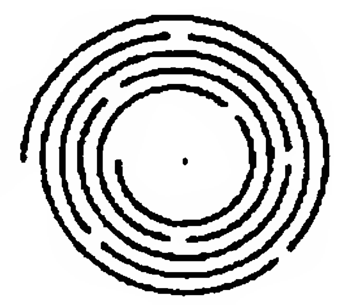

Fig.6

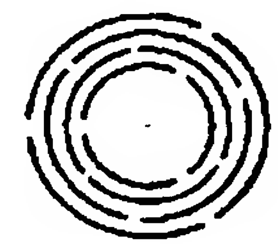

Fig.5

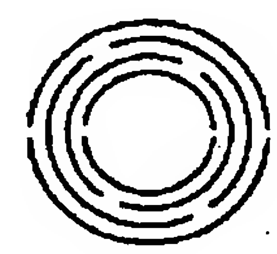

Fig.4

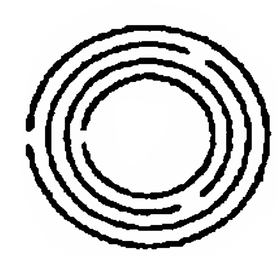

Fig.3

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Sheet 2

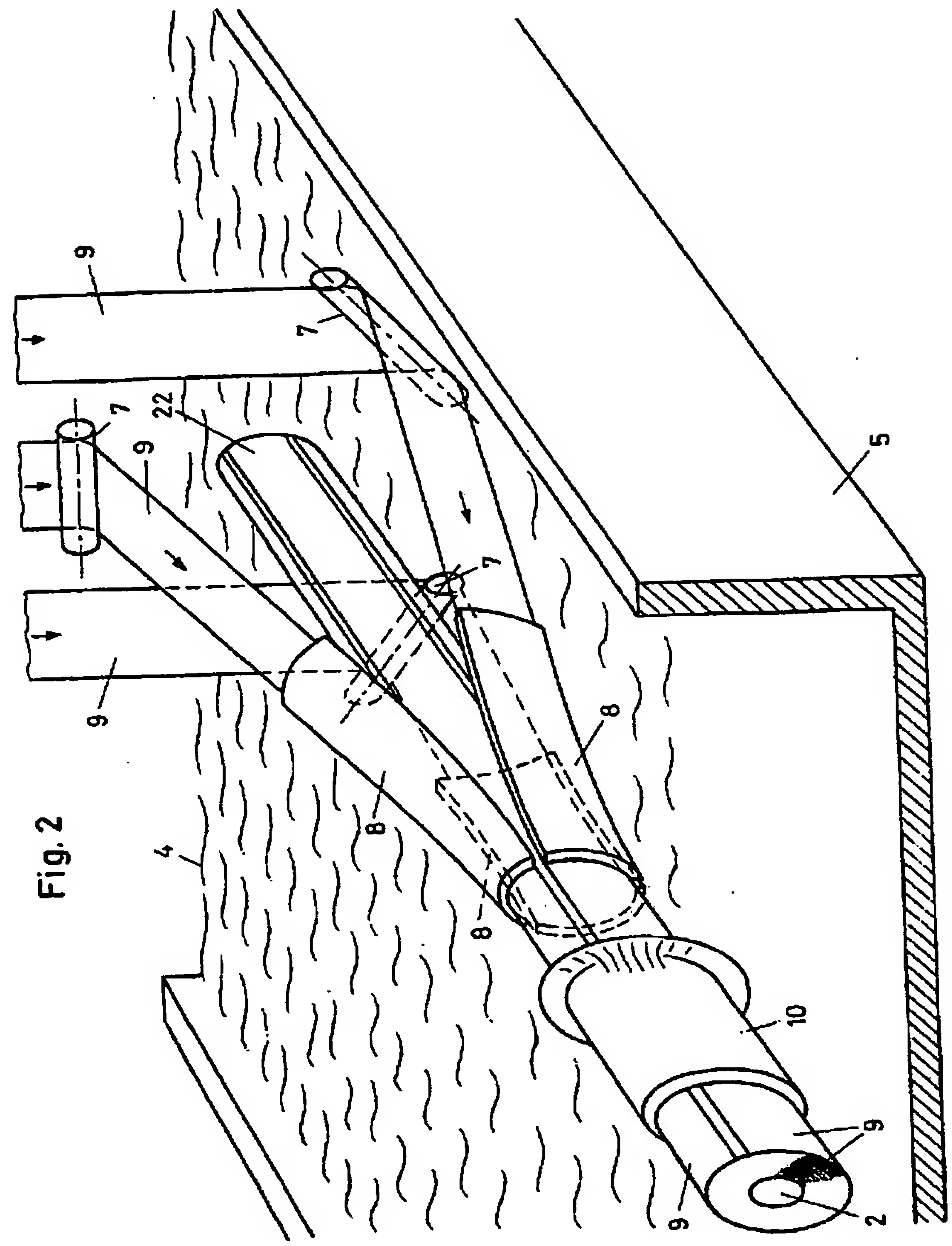

Fig. 2